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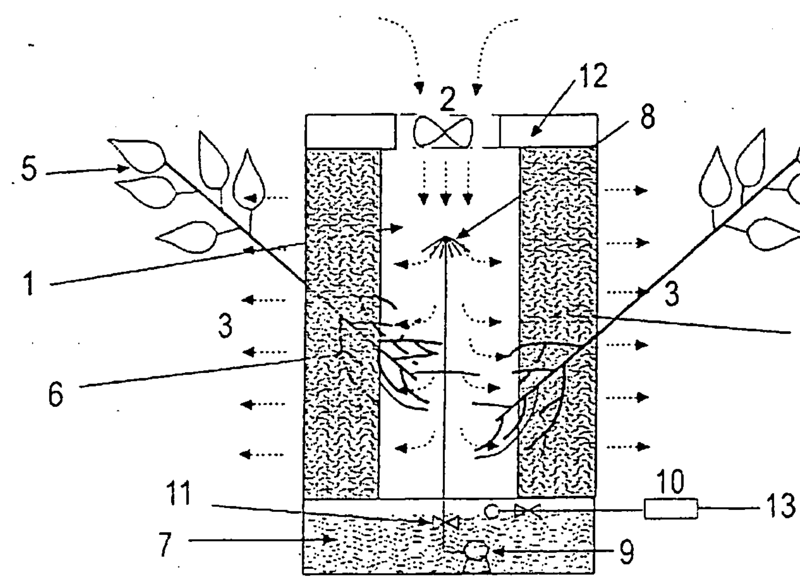
[Continued on next page]

(54) Title: A METHOD AND APPARATUS FOR IMPROVING THE QUALITY OF INDOOR AIR



(57) Abstract: This invention relates to a novel and most efficient method and apparatus for improving the quality of recirculating closed space air. Indoor air pollution is recognized as being a major environmental hazard responsible for the Sick Building Syndrome (SBS) and Building Related Illnessess (BRI). The novel apparatus uses an ecosystemic approach whereby an engineered ecosystem is created, utilizing plants and microorganisms in a three-zone system comprising a bioscrubber, a biofilter and a phytofilter. The resultant system effectively removes particles, volatile organic compounds and other toxic gases, while releasing oxygen and desirable plant exudates to the air.

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A Method and Apparatus for improving the Quality of Indoor Air

The present invention relates to a method and apparatus for improving the quality of recirculating closed space air. Indoor air pollution is recognized as being a major environmental hazard responsible for the Sick Building Syndrome (SBS) and Building Related Ilnessess (BRI). The present invention uses an ecosystemic approach whereby an engineered ecosystem is created, utilizing plants and microorganisms in a three-zone system comprising a bioscrubber, a biofilter and a phytofilter. The resultant system effectively removes particles, volatile organic compounds and other toxic gases, while releasing oxygen and desirable plant exudates to the air.

BACKGROUND OF THE INVENTION

The energy crisis of the 1970's brought about the air-tightening of buildings to conserve energy in heating and cooling. However, the increased use of synthetic materials in building construction and finishing, and the intensive use of computers, and other electromechanical equipment in the workplace has created a situation whereby toxic substances are released into the indoor atmosphere but are not removed. This phenomenon has given rise to the, so called, "sick building syndrome" leading to various health problems, termed Building Related Illnesses (BRIs) such as itchy eyes, skin rashes, drowsiness, respiratory and sinus congestion, headaches and other allergy-related symptoms. This problem derives from various factors, but air-tight sealing of buildings is the dominant factor, because of the various pollutants which build up in the building, and which are recirculated with air.

Indoor air pollution (IAP) has various sources, not excluding outside air pollution, but also synthetic building materials which are known to emit various organic compounds gases. Human beings themselves are a source of indoor air pollution, especially when living in a closed, poorly ventilated area. As reported by Wolverton et al. [B.C. Wolverton, A. Johnson and K. Bounds, "Interior Landscape Plans For Indoor Air Pollution Abatement, Final Report - September 15, 1989, NASA, John C. Stennis Center] literally hundreds of volatile organics, which possibly interact with one

another, exist as pollutants in indoor air, and may affect humans even below present detection limits. The range of airborne pollutants includes volatile organic compounds such as aldehydes (especially formaldehyde) and methylene chloride; aerosol propellants such as CFC's; combustion, respiration and emission products from other processes such as ozone, carbon and nitrogen oxides, and sulfides; airborne pathogens such as viruses, molds and bacteria; particles such as smoke, asbestos and dust; and radioactive gas such as radon and its decay products.

It should also be noted that indoor air pollution is not limited to buildings and is also relevant to other enclosed spaces such as cruise ships, aircraft, spacecraft and underground installations.

The following are solution approaches currently in use:

1. Eliminating sources of pollution

The most effective way of dealing with indoor air pollutants is by preventing the use of substances that may cause them. Yet, building, interior-design industries, and manufacturers of equipment and appliances, are typically reluctant to find substitutes for ingredients of the technologies involved. For example, urea-formaldehyde, the source of formaldehyde, is commonly used in the particle board industry and as adhesives for carpeting, wallpaper, furniture and partitions, and is not easily replaceable with other adhesives. Nevertheless, certain solutions do exist and are practiced mostly in European countries.

2. Ventilation

Much of the hi-rise building stock built since the seventies is not equipped with openable windows because of its reliance on mechanized heating, ventilation and air conditioning systems. In addition, the ability to supply air and artificial illumination away from the building envelope has enabled architects to create "deep" building plans, which have a larger volume to envelope ratio and are thus less expensive to construct and to air-condition. Recent ecological awareness, which covers energy conservation and indoor air quality in particular, is responsible for shifting design trends again towards larger envelope to volume ratios where novel envelope designs provide protected ventilation and higher thermal insulation, in the form of, so-called, "double envelopes" and special ventilation

ducts. However, conversion of existing building stock to better ventilation standards is very costly, and often impractical.

3. Removing pollutants from the indoor atmosphere

Most indoor pollutants originate from within the building, either from the building materials or from human-related activities (use of machines, cleaning, cooking, human emissions, etc.). Pollutants come in several forms: particles (tobacco smoke, dust, pollen, asbestos), gases [volatile organic compounds, machine-emitted, respiration-related (CO_2, vapor), radon], microorganisms (pathogens, spores).

Several methods are being used to capture and remove airborne pollutants from the air. The common denominator of these methods is that they filter the pollutants out of the air by capturing them in other media, either in the form of a solid filter or in water. The task still remains to replace the saturated filter.

An approach that overcomes this drawback is **ecosystemic-based filtration.** This solution involves the use of microorganisms and plants, and occasionally additional living organisms, linked in a symbiotic relationship and housed in a specially designed mesocosm. The biodegrading capabilities of microorganisms, mostly located on plant roots, is combined with the absorption and assimilation capabilities of the plants they reside on and with which they form various types of cooperation. This approach, described in the abovementioned publication by Wolverton et al and elsewhere (John Todd and Beth Josephson 1994), involves using potted plants containing activated carbon filters. Air is circulated through the activated carbon filter and plant roots by means of appropriate fanning ducts provided in the potting soil, thus contacting this air with microorganisms found on the roots, and with the roots themselves.

Filtration apparatus based on the above mentioned principles is described in U.S. patent 5.407.470. Although US Patent No 5.407.470 filters air through the roots of plants, the air flow is treated only by the contact of air with soil and roots of plants.

Additional existing patents describe the filtration of air through plants and/or plant roots (US Patents Nos 5.190.570, 5.217.696, 5.433.923, 4.961.763, 5.397.382, 5.269.094, 5.351.438, 5.397.382, 5.85.460 and 4.732.591).

Prior art based on this approach, however, have considerable drawbacks. Firstly, the pressure drop through systems which require flowing air through potting soil and activated carbon is prohibitive, hence the method cannot be used practically to treat large volumes of air at reasonable prices. In addition, the efficiency of the described filters is limited due to the relatively small numbers of plants grown per surface area of floor. The roots of plants play a very important role in air purification, and the approach of the prior art is limited in this respect, because contact between air to be purified and the potted roots is not efficient, and the total mass of roots in potted plants is also not optimized.

It is therefore an object of the present invention to provide a method and apparatus for indoor air purification, which overcomes the drawbacks of the prior art .

BRIEF DESCRIPTION OF THE INVENTION

The present invention combines the effects of wet scrubbing, bio-filtration and mechano-chemical filtration to achieve an increased removal efficiency for various types of pollutants, namely particles, hydrophilic and hydrophobic materials and gases.

In the present invention the number of plants per square meter of floor area is increased by a substantially vertical orientation of the filtration surfaces on which the plants are grown.

In the present invention there is an addition of non-genetically engineered microorganisms, specialized for the bio-degradation of organic compounds of low bio-degradability, which use these compounds as a carbon source.

The method for improving the quality of recirculating closed space air, according to this invention, comprises the following steps:

1. providing a substantially sealed chamber with air inlet(s) and outlet(s);
2. providing moisture and plant growth nutrients coupled with the said chamber to encourage root growth;
3. providing support media for plants in an adjacent biofilter zone which contains physico-chemical adsorbents;

4. providing plant roots originating in the support media and contained within the above mentioned chamber;
5. providing a nutrient environment devoid of organic carbon sources so the carbon needs of the microorganisms is supplied by the carbon in the airborne contaminants;
6. causing air to flow through the said substantially sealed chamber with roots and microorganisms, and to contact the said support media and roots and microorganisms, whereby air pollutants are removed from the circulating air;
7. recirculating the water generated by the spray in the sealed chamber so that untreated pollutants can pass again through the exposed root mass.
8. recirculating the at least partially purified air obtained from step (6) above to the closed living space;
9. providing means to maintain hydroponic and aeroponic plant growth conditions within the above mentioned chamber.

DETAILED DESCRIPTION OF THE FIGURES

Fig.1 shows schematically an illustrative and non-limiting example of one preferred embodiment of the invention in the form of a vertical column.

In the figure, a substantially sealed chamber (1), known as the 'bioscrubber zone', is provided with air inlet (2) through which an ambient recirculating air is fed. The air is passed to the support media (4) on which plants are grown and emerges into the indoor space through outlets (3). Of course, a plurality of inlets and outlets can be provided as desired, and only one of each is shown in the figure for the sake of simplicity. On the surface of the constraining wall of the treatment chamber (1), plants (5) are grown, the roots of which, (6), are positioned within the chamber (1). At the bottom of the chamber, a moisture reservoir (7) is provided, which contains water and any desired nutrient materials. The solution contained in reservoir (7) is recirculated within the chamber (1) by means of a pump (9) and by any means known in the art and not shown in the figure for the sake of simplicity. Nozzles (8) produce a spray within the chamber in order to create the desired humidity in the vicinity of the roots. A make-up water inlet (13) can be provided to make up for losses of liquid.

Ideally the supply of make-up water (13) which will be provided as a replacement for the evaporated water, would be de-mineralized water that will not cause

accumulation of salts. De-mineralized water can either be produced by an "on-site" R.O. system (10) or by adding de-mineralized water produced elsewhere .

Of course, reservoir (7) can also be located outside chamber (1). Fig. 1 also describes schematically the cover of the apparatus which comprises a cover plate (12) and an air blower (2).

Fig 2 and **fig 3** show different geometrical configurations, namely the 'TallGro' and the 'WallGro' respectively, with similar characteristics.

DETAILED DESCRIPTION OF THE INVENTION

According to the present invention, a system of two complementary filtration zones is created: the **BIOSCRUBBER** zone and the **BIOFILTER** zone. The combination of these two zones achieves a synergistic filtration system. Spray drop created in the bioscrubber chamber serves to remove pollutants from the air and to recirculate it through the biological components of the scrubber and filter zones until they are completely degraded and assimilated. At the same time it irrigates the adjacent biofilter zone. The biofilter zone, in turn, sends out roots into the bioscrubber zone, where the resultant exposed root mass and the microorganisms spread throughout its extensive surface area perform a large part of the adsorption, biodegradation and assimilation of the dissolved pollutants. In addition the biofilter zone dehumidifies the air moistened in the bioscrubber zone. The vegetative biomass feeds on the pollutant and also contributes to the indoor landscape.

Since roots are grown by hydroponic and aeroponic methods, contact between air to be treated and roots is not impeded by surrounding potting soil. Furthermore, as will be apparent to a person skilled in the art, aeroponic growth conditions may lead to a substantially increased root mass, which means that substantially larger amounts of air can be treated in the same treatment chamber. In addition the mass of roots offers lower resistance to the air flow in comparison to other systems described elsewhere. As a result the energy required for cleaning a given volume of air is reduced.

Of course, pre-treatment or after-treatment of air can also done by providing active carbon filters to remove certain pollutants, or by providing any other abatement units. Additional treatments performed on the air before or after it has been at least partially purified by the method of the invention do not substantially affect its effectiveness or usefulness.

The hydroponic environment enables a high degree of control over the roots and their associated microflora. For air containing a few known chemicals the degrading microflora may be restricted to a few species of microbes. The roots are inoculated using pure cultures of microorganisms known to actively degrade the pollutants in question. Examples of bacteria species and the chemicals they biodegrade include varieties of Pseudomonas (for propionaldehyde, butyraldehyde, ethanol), Hyphomicrobium (for methylene chloride), Thiobacillus Xanthobacter and Nocardia (for hydrogen sulfide), fungus species include Cephalosporium, Paecilomyces, Penicillium, Aspergillus, Trichoderma, Mucor, Actinomycetes, Micromonospora, Micrococcus, Rhodococcus and Ovularia (for various malodorous sulphur compounds and ethyl acetate).

A large variety of plants with low-light requirements are candidates for this process, depending on foliage and root characteristics. Among the more promising are Philodendrons, Scindapsus aureus (Golden Pothos), Chlorophytum (Spider Plants) and Aloe Vera, but other species, also known to remove contaminants from the air [Snyder1990, Wolverton1996], can be used.

Plant nutrients supplementing the biodegraded airborne pollutants consist of a combination of hydroponic nutrient solution and an ion-exchange slow release fertilizer. The particular formulae used depend on the plants and the environment in which the system is placed.

As will be apparent to the skilled person, the example shown in Fig. 1 is only a schematic way of carrying out the invention, and many different actual apparatus can be devised. For instance, many different air flow arrangements can be devised, different moisture-providing methods can be used, different geometries and sizes of chambers can be exploited, all without exceeding the scope of the invention.

A blower (1) intakes air and introduces it into ~~a~~ the filter chamber preferably having a vertical configuration and in which three filtration zones are arranged in series as follows

a) A BIOSCRUBBER zone (2), wherein the airflow is intercepted by droplets or a water spray (which may contain plant nutrients in solution) and produced by pumping said water/plant nutrient solution through nozzles (6). Inside the BIOSCRUBBER zone (2) are plant roots originating from the adjacent biofilter zone (b) having the function of providing droplets provide larger contact surfaces among water films and droplets, microorganisms and air in order to improve the removal of particulates and water soluble gaseous contamination. While coming in touch with the airflow, the water droplets are loaded with dissolved oxygen (DO), which later supports the aerobic metabolism of organic pollutants taking place in the filter system.

b) The BIOFILTER zone (3), wherein incoming air from the bioscrubbers zone passes through an absorbent and porous filtering substrate having a low hydraulic resistance to air flow , upon which plants are grown and are irrigated and fertilized by the water/nutrient solution reaching the biofilter with the airflow from the BIOSCRUBBER (2).Thus, the BIOFILTER (3) contains moisture that originates from the BIOSCRUBBER (2) droplets or mist, thus dehumidfying the air that passes into the next phytosphere filtration zone.

c) The phytosphere filtration zone (4) consisting of the vegetative parts of plants grown on the Biofilter substrate. Air blown by blower (1) reaches the said phytosphere zone (4) from the BIOSCRUBBER and the BIOFILTRATION ZONES ((2) and (3) respectively). As the air passes through this zone it is enriched with oxygen and possible aromatic exudates.

The system functions, for example, in the way described below (see fig.1). A blower (1) blows indoor air to be filtered into the BIOSCRUBBER zone (2) where it passes through a mist of water/nutrient which adsorbs most of the pollutants (gases and/or particles) contained in it. The mist settles on the extensive surface area of the plant roots growing into the BIOSCRUBBER zone (2). The microorganisms growing in the system draw carbon from the pollutants dissolved in the water and minerals from the

nutrients solution. Plants in turn, take up the metabolites of the microorganisms, freeing the BIOSCRUBBER and BIOFILTER for further operation. This is the regenerative quality of this ecosystemic filter. The adsorbing water solution is recycled through the BIOSCRUBBER region so pollutants not absorbed by the biomass during the first pass can be subsequently removed thereby increasing the length of time the filter operates while economizing in operating and regenerating costs.

The humid air-stream and the water spray from the BIOSCRUBBER zone (2) are transferred to the BIOFILTER zone (3) where it moistens the surface of the particles of the filter substrate, which, in turn, increases the absorbing capability of the substrate to remove various air pollutants.

It is possible to grow plants in the BIOFILTER zone (3), so that the rhizosphere (roots, microorganisms and substrate) will increase the effective surface area of the filtering substrate and will constitute a growing substrate for microorganisms, which will increase the metabolic capability and the decomposition of organic compounds in the BIOFILTER zone (3). By positioning the biofilter zone vertically it is possible to increase the number of plants and roots per given floor area.

The filter includes a reservoir for water and nutrient solution (5) to collect the drainage from the BIOSCRUBBER and BIOFILTER zones ((2) and (3) respectively). This water and nutrient solution is recirculated in the system by a pump (7). The system is equipped with a system for water replenishment.

Claims

1. An air filtration system for indoors air purification comprising:

   a. A blower that introduces air into a filter

   b. A filter comprising three filtration zones that are arranged in series as follows:

      i) a BIOSCRUBBER,

      ii) a BIOFILTER, upon which plants may be grown, and

      iii) the phytosphere (upper-plant) zone.

   c. A reservoir for water and nutrient solution to collect the drainage from the filter

   d. A pump to recirculate the water and nutrient solution

   e. A system for water replenishment

2. A combined filtration system as in claim 1 wherein said filter is arranged in a vertical configuration.

3. A combined filtration system as in claims 1 and 2 but without plants.

4. A combined filtration system as in claims 1, 2, 3 but said operating is in an opposite filtering direction i.e., the blower takes the inflow air into the filter from the upper-plant zone into the BIOFILTER zone and finally through the BIOSCRUBBER zone.

5. A combined filtration system as in claims 1, 2, 3, 4 whereas various filtration additives, used for enhancing the efficiency of removal. such as activated carbon, or granules of slow release fertilizers which are added into the BIOFILTER zone.

6. A combined filtration system as in claims 1, 2, 3, 4, 5 where bacteria are added artificially into the system in order to enhance the degradation of one or more pollutants.

7. A combined filtration system as in claims 1, 2, 3, 4, 5, 6 where the filter system is simplified by not including the automatic water level control system and where water is added and changed manually.

8. A combined filtration system as in claims 1, 2, 3, 4, 5, 6, 7 where all or part of the water added to the system are first treated by reverse osmosis (RO) or de-ionization in order to prevent accumulation of minerals as a result of water evaporation and/or evapo-transpiration from the filter.

9. Any filtration system in which an aeroponic system, used for plants growing, is used for indoor air filtering by passing the air through the rhizosphere and the phytosphere zones of the aeroponic system.

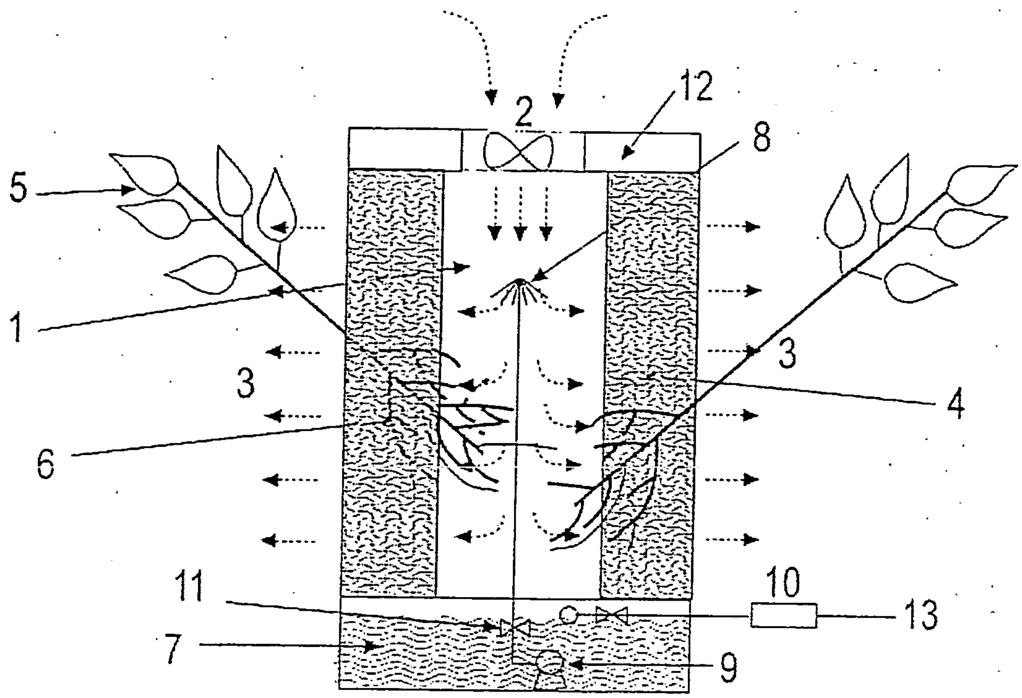

Fig.1

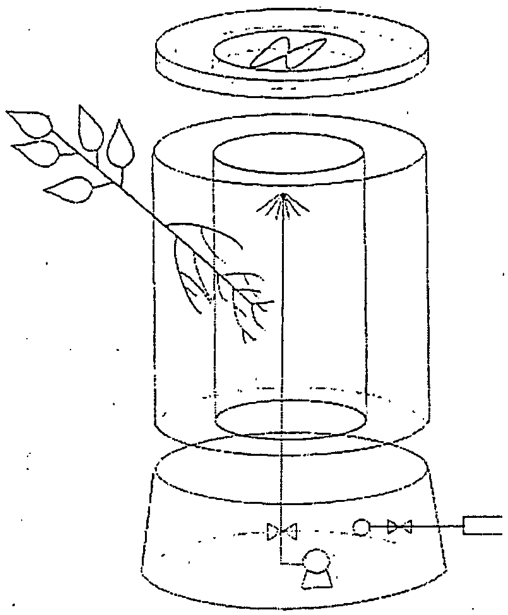

fig.2

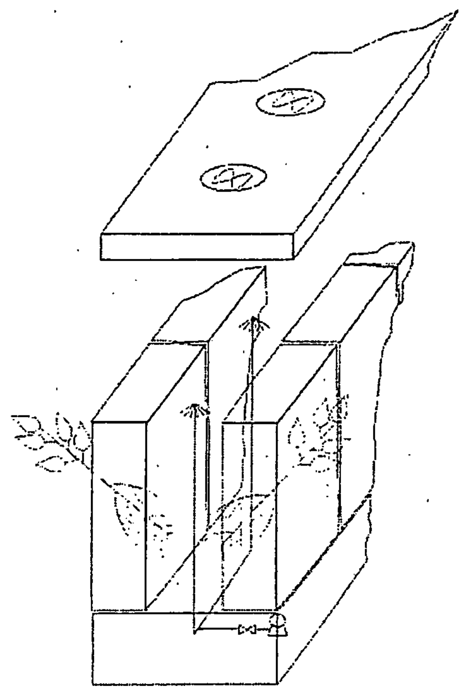

fig.3

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(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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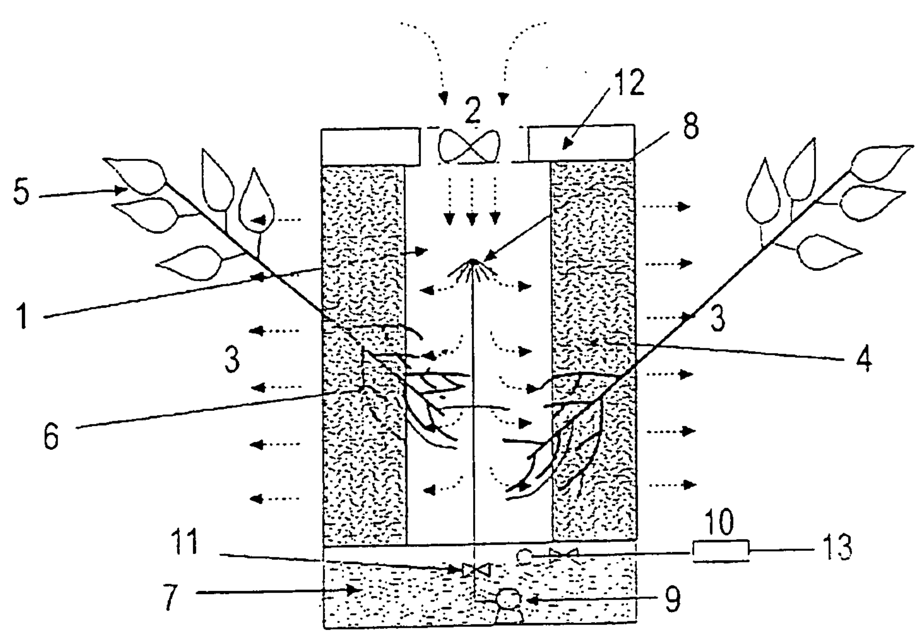

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A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : A61L 9/00; B01D 53/04
US CL : 96/108, 361; 422/122; 47/62A, 83; 55/385.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 96/108, 222, 290, 355, 361, 396; 55/385.1, 421, 471; 422/122; 47/59R, 62A, 66.6, 79, 83

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2002000709 A (DENSO CORP) 08 January 2002 (08.01.2002), abstract; paragraphs 0005, 0011, 0028-0034, figure 1	1-5, 7, 8
X	US 5,089,036 A (HAWES) 18 February 1992 (18.02.1992), figures, col. 3, lines 20-48, col. 5, lines 26-67, col. 6, lines 43-48	1, 2, 4-6
X	US 5,853,460 A (ALCORDO) 29 December 1998 (29.12.1998), figures, col. 3, lines 19-61	9
A	US 5,397,382 A (ANDERSON) 14 March 1995 (14.03.1995)	1-9
A	US 5,217,696 A (WOLVERTON et al) 08 June 1993 (08.06.1993)	1-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
20 May 2003 (20.05.2003)	24 JUN 2003

Name and mailing address of the ISA/US	Authorized officer
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Continuation of B. FIELDS SEARCHED Item 3:
DERWENT
search terms: plant, soil, filter